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Magnification Factor in Partial Capacity Design for Multitude Bay Buildings

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Abstract. Partial capacity design (PCD) is an alternative method to design earthquake-resistant structures. PCD leads to a partial side sway mechanism as its collapse mechanism. Therefore, a magnification factor is applied in designing elastic column (usually perimeter column) in order to make it stronger than the plastic columns. The purpose of this research is to try a proposed magnification factor for buildings with long span. Two concrete buildings located in Surabaya at soft soil, consists of 6- and 10-story, were studied. Each building has 9 spans in the *x*- and *y*-directions, each 8 meters in length. The buildings were designed with the same columns dimension. The elastic columns were located in the building perimeter. The buildings were evaluated using non-linear time history analysis which shows that partial side sway mechanism was achieved.

Keywords: partial capacity design, partial side sway mechanism, magnification factor

1. Introduction

Partial capacity design (PCD) is one of the alternative methods to use in moment resisting frame structure. Unlike capacity design, PCD leas partial side sway mechanism as its collapse mechanism which allows some interior columns and all beams to be plastic while exterior columns (usually perimeter column) are kept to be elastic during the targeted seismic load. This mechanism offers a shorter design procedure because column design can proceed together with beam design based on ultimate load combination.

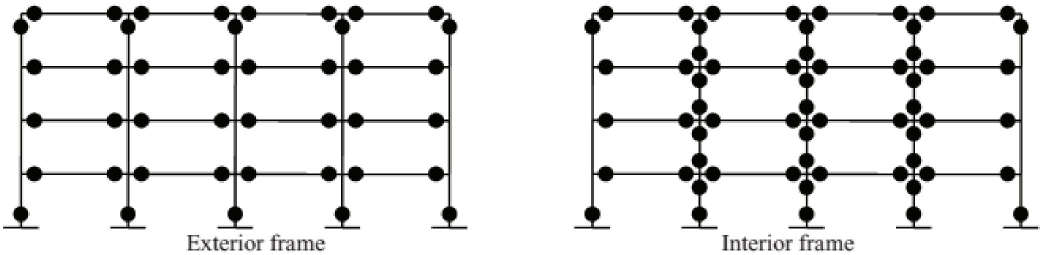

Figure 1. Partial Capacity Design Mechanism

During the targeted seismic load, PCD assumes that interior columns sustain the shear force up to nominal seismic load. Then the excess of shear force is sustained entirely by the exterior columns. To ensure the exterior column could sustain the excess shear force, magnification factor (Muljati and Lumantarna, 2011) was introduced to multiply the capacity of the exterior column.

$$n_{ex} \times S_{ex}^{T} = V_{t}^{T} - f_{1} \times n_{in} \times S_{in}^{T} \tag{1}$$

Where n_{ex} and n_{in} are the total number of exterior and interior columns; $S^{T}{}_{ex}$ is the shear force in the exterior column due to the target seismic load; $S^{N}{}_{in}$ is the shear force in the interior column due to the nominal seismic load; f_1 is the overstrength factor; and $V^{T}{}_{t}$ is the total base shear due to the targeted seismic load. The assumption load distribution of PCD is shown in **Figure 2.**

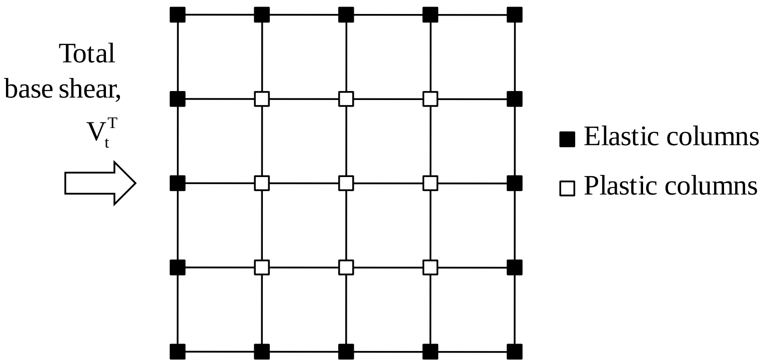

Figure 2. Load Distribution in PCD

In order to maintain the exterior columns to remain in elastic condition during targeted seismic load, a magnification factor was introduced to ensure the capacity of exterior column is larger than the interior column. The magnification factor of the external columns' shear force is derived from (Muljati and Lumantarna, 2011):

$$\mathrm{MF} = \frac{\left(\frac{C^{T}}{C^{500}}\right)\mu - 1.6\left(n_{in} R_{in}^{N}\right)}{\left(n_{ex} R_{ex}^{N}\right)} \tag{2}$$

where C^T is the spectral acceleration of the target seismic load; C^{500} is the spectral acceleration of a five hundred years return period earthquake; μ is the structural ductility; n_{in} and n_{ex} are the total number of interior and exterior column; $R^{N}{}_{in}$ and $R^{N}{}_{ex}$ are the ratio of interior and exterior columns' base shear to the total base shear due to the nominal seismic load.

To be noted that during the application of the targeted seismic load the structure already in the non-linear stage, the spectral acceleration due to the five hundred years return period earthquake, C^{500} should be obtained from the non-linear response spectrum. Therefore, it is proposed to obtain

C^T using the natural period in "plastic period" $T_{plastic}$ from targeted response spectrum (Muljati and Lumantarna, 2011)

$$T_{plastic(predicted)} = 2.969T_{elastic} + 0.313 \quad (3)$$

The procedure to obtain C^T can be seen in Figure 3.

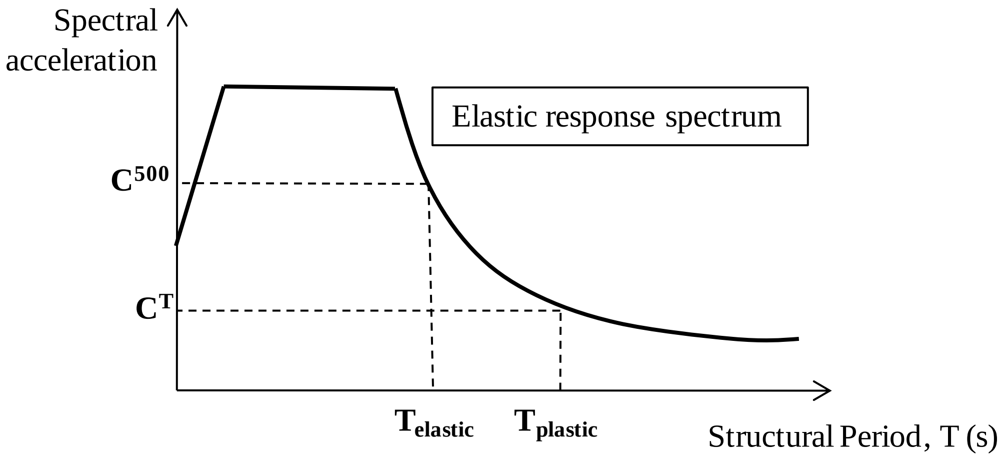

Figure 3. Spectral Acceleration

Previous researches show that the empirical formula of MF is valid to be applied in PCD method especially for regular fully ductile moment resisting frame up to 10-story (Muljati and Lumantarna 2011) and also reported applicable for moment resisting frame structures with vertical set-back (Lumantarna and Pudjisuryadi, 2012). However, the recent research using minimum reinforcement as its design criteria (Muljati and Lumantarna, 2013) in the multitude bay structure shows poor failure mechanism. Therefore, the aim of this study is to validate the MF formula for multitude bay structures.

2. Observed Structures

This study use two symmetrical fully ductile concrete moment resisting frames consist of 6- and 10-story, equal span of 8 meter and story height of 3.5 meter and two target seismic load are used (design and 500 year return period). The layout of the structures can be seen at Figure 4.

These buildings are assumed to be built in soft soil, Surabaya, Indonesia and designed based on the Indonesian Seismic Code (SNI 03-1726-2012) using the PCD method and the MF formulation. Columns use uniform dimension, and perimeter columns are assigned as the elastic column (**Table 1**).

The performance of the structures are checked by nonlinear time history analysis using SAP 2000 Nonlinear (CSI, 2007) with the consistent ground acceleration spectrum, modified from N-S component of El-Centro 1940. Also, the structures are checked with target seismic load of design, 500, 1000 and 2500 return period. The modification is achieved using Seismomatch (Seismosoft, 2011). Moment-rotation relationship is modeled as bilinear using Cumbia (Montejo, 2007).The acceptance criteria for evaluating structural performance are based on failure mechanism of the structure.

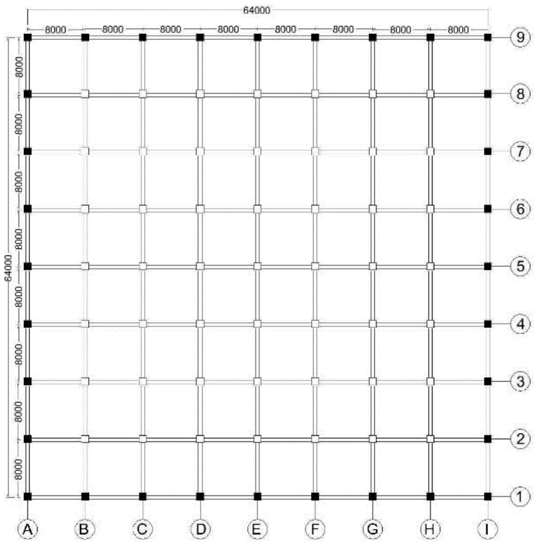

Figure 4.Structural Plan

Table 1. Structural Properties and Dimension

Floor	6-Story			10-Story	
	6-A, C^T = Design	6-B, C^T = Design	6-C, C^T = 500 Year	10-A, C^T = Design	10-B, C^T = Design
	[mm^2]	[mm^2]	[mm^2]	[mm^2]	[mm^2]
9 - 10	-	-	-	500 x 500	700 x 700
7 - 8	-	-	-	550 x 550	700 x 700
5 - 6	500 x 500	650 x 650	500 x 500	600 x 600	700 x 700
3 - 4	550 x 550	650 x 650	600 x 600	650 x 650	700 x 700
1 - 2	650 x 650	650 x 650	700 x 700	700 x 700	700 x 700
Column Concrete Grade = f'c 30 MPa Beam Concrete Grade = f'c 25 MPa Rebar Grade = fy 400 MPa				Secondary Beam = 300 x 600 Girder Beam = 350 x 700 Slab Thickness = 120 mm	

3. Results

The summary of failure mechanism of all structures are shown in **Table 2**. The yielding of plastic columns in model 6-A and 10-A, which are using C^T equal to design seismic load, resulting unexpected condition, leading to soft story mechanism and even yielding at the elastic columns. However, model 6-B, 6-C and 10-B that are using C^T equal to design seismic load and a same dimension of column in each story, shows a good result and partial side sway mechanism was achieved.

Table 2. Summary of Structural Mechanisms

Structure	Model	Seismic Return Period	Structure Mechanism
6 Story	6-A	200	Fracture occurred at plastic column story 3, leading to soft story failure.
		500	Fracture at elastic and plastic column at story 3, resulting in structural collapse. T = 3 second
		1000	Fracture at elastic and plastic column at story 4, resulting in soft story failure. T = 2.9 second
		2500	Fracture at plastic column at story 4, elastic column experiencing yielding. T = 2.88 s
	6-B	200	Structure survives under 20 second excitation and fulfill the Partial Sidesway mechanism
		500	Structure survives under 20 second excitation and fulfill the Partial Sidesway mechanism
		1000	Structure survives under 20 second excitation and fulfill the Partial Sidesway mechanism
		2500	Structure survives under 20 second excitation and fulfill the Partial Sidesway mechanism
	6-C	200	Structure survives under 20 second excitation and fulfill the Partial Sidesway mechanism
		500	Structure survives under 20 second excitation and fulfill the Partial Sidesway mechanism
		1000	Structure survives under 20 second excitation and fulfill the Partial Sidesway mechanism
		2500	Structure survives under 20 second excitation and fulfill the Partial Sidesway mechanism
10 Story	10-A	200	Structure survives under 20 seconds excitation, although structure exhibits soft story mechanism at story 7
		500	Fracture occurred at plastic column story 7 and at yielding at elastic column at story 6 to 8. T = 8.56 second
		1000	Yielding at elastic column and fracture at plastic column story 5, T = 7.88 seconds
		2500	Fracture at plastic and elastic column at story 5, resulting in soft story mechanism. T = 7.9 second
	10-B	200	Structure survives under 20 second excitation and fulfill the Partial Sidesway mechanism
		500	Structure survives under 20 second excitation and fulfill the Partial Sidesway mechanism
		1000	Structure survives under 20 second excitation and fulfill the Partial Sidesway mechanism
		2500	Structure survives under 20 second excitation and fulfill the Partial Sidesway mechanism

4. Conclusions

The MF using C^T equal to 500 years seismic return period and C^T equal to design seismic load with typical column dimension also shows a good result. However, when the column dimension is vary, soft story was occurred. It is suggested to used a typical column dimension to avoid this soft story failure.

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